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ASSESSMENT OF FATIGUE IN DIVISION I FEMALE SOCCER PLAYERS BY WEEKLY
MEASUREMENT OF COGNITIVE SPEED AND POWER OUTPUT

By

Lisa Christine Martin C.S.C.S., F.M.S.

B.A., University of Louisville, 2005

A Thesis

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University of Louisville

Louisville, Kentucky

May 2012

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A Thesis Approved on

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ABSTRACT

ASSESSMENT OF FATIGUE IN DIVISION I FEMALE SOCCER PLAYERS BY WEEKLY MEASUREMENT OF COGNITIVE SPEED AND POWER OUTPUT

Lisa C. Martin

April 20, 2012

Accumulated fatigue experienced during the competitive season can be detrimental to athletic success. The purpose of the study was to identify a performance test that best correlated with markers of fatigue in an attempt to detect accumulated fatigue. The performance markers included vertical jump height (VJ), peak power output (PPO) and reaction time (RT). The markers of fatigue included weight, stress levels (DALDA), resting heart rate, training load, rating of perceived exertion (RPE) and ratio of RPE to training load. Seventeen female subjects, members of the Division I University of Louisville's soccer team, volunteered to participate. RT, RPE, and 'worse than normal' responses in part A and B of the DALDA questionnaire significantly decreased. RT significantly positively correlated with 'worse than normal' responses in the DALDA questionnaire. This pilot study provides evidence that RT can be used as a tool that identifies markers of fatigue.

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INTRODUCTION

Fatigue is defined as loss of muscle force, exercise capacity, endurance, power or an increase in rating of perceived exertion [1] and can be experienced while performing a specific short task or may accumulate over time, ultimately causing staleness, or overtraining. An athletes' adaptation to training is varied and depends on the volume and intensity of the stimulus, with fatigue as an accepted part of the process. Assessing the severity and duration of the imposed fatigue is critical when designing and implementing training programs, especially during the competitive season for a collegiate athlete. Overreaching is the term used when restoration of performance capacity takes days or weeks and overtraining is the term used when restoration of performance capacity takes weeks or months [2]. When athletes do not fully recover within the planned recovery period, performance decrements will likely interfere with training and competition and may lead to detraining.

Optimizing recovery in athletes is a critical for maintaining peak performance during entirety of the competitive season. In addition to providing adequate rest, the identification and early detection of overtraining symptoms is necessary to prevent overtraining. Symptoms of fatigue are extensively represented in the literature. Since the most accepted sign is a decrement in performance, tracking performance variables after pre-planned recovery periods seems logical. The performance variables should be sport specific, easy to integrate into training sessions, affordable, objective, not able to be manipulated or overly physically taxing [3].

Currently, there is no standardized performance tracking protocol (or test) recommended for measuring fatigue in athletes participating in team sports during their competitive season. In

this study, two performance variables that fit the above testing guidelines [3] were tracked weekly over the course of a Division I women's soccer season. Lower body power assessed through a countermovement jump (CMJ) test and psychomotor speed assessed through a reaction time test, were used to measure under-recovery in this study. Evidence from previous studies support that CMJ is an effective and non-fatiguing tool used to monitor athletes over the course of a season [4-6]. Psychomotor speed, defined as the ability to rapidly and accurately perform body motor movements, has only recently been used to detect under-recovery in athletes [7, 8]. Peak power output (PPO), vertical jump height (VJ) and reaction time (RT) were tracked weekly as markers of fatigue and compared with a variety of performance variables including: a) resting heart rate (HR), b) rating of perceived exertion [9], c) bodyweight [6], d) body composition, e) self-reported levels of stress captured by the Daily Analyses of Life Demands For Athletes (DALDA), and, f) daily training load (TL).

The purpose of this study was to identify the performance test that best correlated with reported markers of fatigue in an attempt to monitor recovery during the 2011 National Collegiate Athletic Association Division I soccer season. Based on current literature, it was hypothesized that VJ and PPO would correlate best with WT and body composition parameters since strength plays a critical role in VJ. It was also hypothesized that RT would correlate with DALDA, resting HR, RPE, and TL, since these parameters represent absolute training load and fatigue associated with central nervous system.

LITERATURE REVIEW

INTRODUCTION AND TERMINOLOGY

Effective training principles include overload and specificity which induce short term fatigue to promote positive adaptation for the athlete. Fatigue is defined as loss of muscle force, exercise capacity, endurance, power or an increase in rating of perceived exertion [1]. Fatigue that occurs due to failure of mechanisms within the working muscle is called peripheral fatigue. Underlying mechanisms for peripheral fatigue include impaired reuptake of calcium, impaired oxidative phosphorylation, impaired interaction between actin and myosin cross bridging, impaired calcium release from sarcoplasmic reticulum, and loss of electrical conduction from muscle membrane to tubule system [10]. Exercise-induced fatigue that occurs due to failure in mechanisms of the central nervous system is defined as central fatigue. Central fatigue can originate in the cerebral cortex through reduced motivation or impaired descending neurological drive, due to increased inhibitory interneuron input to the motor cortex [11]. Central fatigue can also originate in the spinal cord caused by impaired alpha motor neuron firing rates [1]. Most research supports that fatigue is more commonly caused by peripheral factors [12].

Fatigue, whether peripheral or central, can limit or completely inhibit performance. Fatigue can fall anywhere on the continuum between task failure, which is defined as the inability to maintain maximal force during a task, and overtraining syndrome and therefore needs further distinction. While task failure takes place within the athletes' competitive season at various times and sometimes has no lasting negative effect, the effects of overtraining produce longer lasting impairment to the athletes' performance.

Nederhof et al has supported new terminology to differentiate between overtraining and overreaching [3]. Short term overreaching producing temporary fatigue managed within a planned period of recovery is called functional overreaching. In non-functional overreaching, full recovery does not occur after the planned recovery period. The severity of symptoms and time to recover that separates functional overreaching, non-functional overreaching, and overtraining syndrome [3]. Overtraining and overreaching have been diagnosed in athletes where prolonged performance decrements coincide with clinical psychological symptoms and history of increased training while other pathologies have been ruled out [3, 13-15]. Other authors have coined the term *overreaching* to describe an accumulation of training inducing *short term* performance decrements with or without psychological or physiological symptoms of overtraining in which restoration of performance capacity may take several days or weeks. They use the term *overtraining* to describe an accumulation of training resulting in *long term* performance decrements with or without psychological or physiological symptoms of overtraining in which restoration of performance capacity may take several weeks or months [2]. Here, the time to restore performance distinguishes the two rather than severity of decrements. The lack of uniform description of overreaching vs. overtraining hinders research findings in identifying ways to deter from either.

CONSEQUENCES OF FATIGUE

Persistent fatigue, resulting from overtraining, non-functional overreaching or functional overreaching, occurring during the competitive season is detrimental to the athlete's performance and team's success. If an athlete does not fully recover within the planned recovery period, the performance decrements incurred will likely interfere with competitions. Prolonged recovery promotes detraining in athletes. Overtraining causes relative or absolute overload on the musculotendinous unit, which compromises 67% of injuries in sport [16]. According to Gabbett and Jenkins, there is a significant relationship between high training loads and injuries in rugby players [17]. Due to these unfavorable results, managing fatigue is critical for maintaining peak performance throughout the competitive season. Social stressors, capacity to buffer stress and

total regeneration time and techniques have been found to correlate with the performance decrements and time to recover [3]. In addition to providing adequate rest, the identification and early detection of markers is necessary to prevent the detrimental side effects of overtraining.

MARKERS OF OVERTRAINING

Because fatigue is dependent on the task and time performing a task, the symptoms vary significantly. Familiarizing the athlete and sports practitioner with the symptoms is the first step to measure fatigue. Once symptoms have been identified, they should be monitored after preplanned recovery periods to detect persistent fatigue. If the symptoms present after adequate rest, the athlete may be experiencing accumulating fatigue that could interfere with sport performance. The identified symptoms of fatigue include decrements in sport performance [18], negative mood states [19], depression [20], increased heart rate variability [21], increased [22] and decreased resting heart rate [23], lowered blood lactate levels [13, 24], increased rating of perceived exertion [25], weight loss [20, 26], altered body composition [8], decreased VO_2max [27], hormonal changes [20, 28], disturbed sleep [29], and loss of appetite [20]. In this study, the following markers of fatigue were collected for reasons of validity and convenience and therefore, will be further reviewed; resting heart rate (HR), rating of perceived exertion [9], bodyweight [6], body composition, perceived levels of stress and daily training load (TL).

Rating of Perceived Exertion

RPE is the individual's perception of effort at any given time during physical activity. Physiological fatigue is associated with increased perception of exertion [1]. The traditional and validated scale is called the Borg Rating of Perceived Exertion Scale [30]. This numerical scale ranges from 6 to 20, in which increasing numbers correlate with increasing sense of effort experienced by the individual exercising. The brain weighs exercise intensity against environmental conditions and predetermines endurance, measured by changes in RPE [1]. RPE is viewed as the central control of avoiding muscle damage. The perception of effort is influenced by temperature, psychological state, anxiety, hydration and afferent feedback from working

muscles and their physiological environment [25]. Sensation of fatigue will elevate rating of perceived exertion due to peripheral and central inputs [25]. RPE has been found to increase with intensified training as a response to accumulated fatigue [31] and also indicate when adaptation to training occurs [32].

Recent studies have determined the ratio of RPE and actual training load measured in watts or blood lactate as criterion for overtraining [13, 23]. Snyder et al discovered an increasing ratio between RPE and exercise intensity expressed by blood lactate levels in overtrained athletes [13]. Lactate levels decrease in overtrained athletes while RPE stays the same resulting in higher RPE:La ratio. The ratio between RPE and exercise intensity expressed by heart rate would likely follow the same increasing trend in overtrained athletes. Submaximal and maximal heart rate has been found to decrease in overtrained athletes [23, 27, 33], meaning the exercise intensity would decrease in overtrained athletes much like blood lactate levels do. RPE would likely stay the same or increases due to the increased sense of fatigue at these workloads.

Resting Heart Rate

HR has been shown to be affected by training stimulus both during and after exercise. Historically, elevated resting HR has been shown to be a marker of overtraining [22, 34]. However, some studies have shown that resting HR can decrease or not change in overreached athletes [23, 31]. Further investigation led to findings that both elevated resting heart rate as well as decreased resting heart rate may be observed in overreached athletes [35]. Overtraining leads to hormonal imbalances [15]. Hormone imbalances lead to autonomic imbalances which shift parasympathetic and sympathetic outflow away from normal. In 1976, Israel coined two types of autonomic imbalance as 1.) Addison type and 2.) Basedow type in which the parasympathetic or sympathetic influence dominates in the subjects' resting state, respectively [15]. Research has been somewhat controversial on deciding which type dominates during certain activities. Kuipers has postulated that the sympathetic type dominates in early overtraining whereas the parasympathetic type dominates in the advanced stages of the overtraining syndrome [15]. Lehmann et al hypothesize that the sympathetic type overtraining

syndrome occurs in the presence of accompanying psycho-emotional stress, such as too many competition and non-training stress [35]. In another study, Lehmann et al explains that the sympathetic type dominates in explosive sport athletes, whereas the parasympathetic type dominates in endurance athletes [33]. Also worthy of noting, highly trained athletes have lower resting heart rates than their sedentary counterpart [36], making the parasympathetic overtraining type hard to detect.

Body Composition and Weight

Body composition and simple weight [6] measurements are easy to collect and are considered objective markers of overtraining. Decreased body fat has been identified as a marker of overtraining [8, 31]. Research has shown varied results when examining the effects of the competitive soccer season on body composition. Kraemer et al discovered an increase in body fat in non-starters of a Big-Ten soccer team during their competitive season with no significant body fat changes in the starters [6]. Another study using English league soccer players as subjects found no change in body fat percentage throughout the season [37]. WT is also identified as a marker of overtraining, but research shows conflicting results. Kellmann noted that WT loss is a symptom of overtraining [20, 31]. Frykman et al discovered WT loss to be a result in overloading two ski trekkers [26]. Some found no change in weight with increased exercise intensity [23, (Callister, 1990 #933)].

Psychological State

Disturbed mood is a widely accepted marker of fatigue and mood is associated with the stress individual's experience. The capacity of an athlete to perform their sport depends on the number of stressors which exist at any particular time [38]. "The Daily Analyses of Life Demands for Athletes" (DALDA) is a reliable and valid tool used in measuring stress experienced by the athlete [39, 40]. There are two parts to the self report questionnaire; part A lists nine general stress sources including, home-life, school/work, friends, training, climate, among others, and part B lists twenty five stress related symptoms including temper, boredom, tiredness, irritability,

interest, and congestion, muscle soreness, among others [40]. Individuals were asked to rate whether the stress source and stress symptom was 'worse than normal', 'normal', or 'better than normal'. The sum of 'worse than normal', 'normal' and 'better than normal' responses was recorded. If the number of 'worse than normal' responses increases markedly, the athlete can be identified as unable to cope with the stress of life at that time [39]. Studies found significant differences in overreached athletes' 'worse than normal' responses in part B of the DALDA questionnaire [41, 42]. Increased training loads usually produce fatigue and therefore longer recovery periods and cause athletes to experience more training-stress symptoms that are worse than usual [39]. If training load decreases for three consecutive days, but the number of 'worse than normal' responses is still markedly increased for these three days, the subject can be determined as overtrained [39]. In a study done by Coutts et al, sixteen triathletes underwent intensified training for four weeks and a taper period of two weeks and subjects completed DALDA questionnaires daily [41]. The intensified training group demonstrated a significantly higher number of 'worse than normal' responses than the controlled training group during the 4 week training period. During the taper period, the intensified training group demonstrated significant decrease in 'worse than normal' responses in the first week of the taper [41]. The use of the DALDA questionnaire has been extensively used in research linked to intense training [31, 41, 42]. Although it is recommended to use the DALDA questionnaire daily or on alternating days [39], the sensitivity of the questionnaire is not reduced if used weekly [42]. Literature shows that mood state deteriorates before a drop in performance occurs and parallels training load [29, 43].

DECREMENT IN PERFORMANCE

The most obvious and accepted sign of fatigue during a training session is a decrement in performance. A decrement in performance is a product of a deliberately planned program to progressively overload an athlete to improve physical capabilities. Because a decline in performance is what defines overtraining as well as overreaching [44], these declines must be quantified, collected and monitored to show that overreaching or overtraining is indeed occurring.

Supercompensation occurs once adequate rest is provided and results in improved performance. If performance is measured and unchanged throughout a season after increased training load, the subject cannot be diagnosed as overreached [2]. During a team sport competition or training session, declines in performance can appear as a decrease in whole body work rate/velocity or increased rest periods, decrease in technical execution, decrease in kicking velocity (lower limb muscle fatigue), or increase in errors and mental lapses [25]. Finding tests that represent the physical and mental demands of the sport is critical to monitoring the declines in these areas that may be indicative of overtraining.

Current Diagnostic Tools

Many scientists who have researched overtraining have used similar guidelines for diagnosing overreached or overtrained individuals. Many authors have only cited how to generally diagnose athletes as overtrained- history of increased training [14, 44], ruling out other diseases [14, 44-46], and prolonged decrease in performance in combination with mood disturbances [21, 44, 45] have been identified criterion for the diagnosis of overtraining.

What to Test

A decrement in performance is the most widely accepted symptom of overreaching. Thus, tests to measure fatigue should be aimed at assessing decrements in performance. Currently, there is no standard performance test to measure fatigue for athletes participating in team sports. In general, performance is defined as the execution of an action [47]. Sport performance is more complex to define due to the wide range of variables that contribute to sport performance- including technical, physical, decision making and psychological skills [25]. When measuring declines in sport performance, all these variables of performance should be taken into account. Physically, tests that assess changes in muscle force, power, stride frequency, range of motion or speed should be used [25]. Technically, tools that measure changes in motor skills- such as foot speed- or motor skill outcome- such as ball velocity and accuracy should be used [25]. Psychologically, tools to detect changes in motivation and anxiety should be used. Overall,

it is advised to use an assortment of tools to measure various parameters of overtraining [46]. Anaerobic power and cognitive fatigue are performance tests that have been proved to indicate fatigue [4-7, 26].

When to Test

All training sessions and matches will induce a degree of fatigue. Performance decrements that persist after planned recovery need to be monitored. Overreaching is defined as decrements in performance lasting days to weeks and overtraining is defined as decrements in performance lasting weeks to months. Therefore, in order to monitor persisting fatigue, tests should be done after the preplanned rest period. Current recommendations are that athletes take one day of passive recovery per week [3]. Furthermore, the NCAA mandates one entire day off for athletes every seven days. In well planned training programs, athletes should be fully recovered after this day of rest to ensure they are able to train efficiently the other 6 days of the week and perform maximally during competitions.

How to Test

Nederhof et al identify six criteria that should be met in order for accurate measurement of markers of overreaching. The markers should be objective, applicable in training practice, affordable to offer wide spread use by athletes, not able to be manipulated or overly physically demanding, and selection of markers should be based on theoretical framework laid out by evidence from research [3]. Laboratory tests aren't as desirable as field tests due to their non representative conditions of sport training and competition [25]. As Fry et al describe, the best way to monitor changes in performance is by comparing post-training performance results to pre-training performance results done with as much control of other contributing factors as possible [46]. Comparing an athlete's performance to overall norms may not be as sensitive to the individual differences [46].

COUNTERMOVEMENT VERTICAL JUMP

Physiologic fatigue is defined as a decrease in power, or the velocity of a muscular contraction [1]. The countermovement vertical jump (CMJ) is a validated and frequently used tool to assess anaerobic power [48-50]. Vertical jump height (VJ) can be used to determine peak power output [48]. The CMJ assesses power of the muscles of the lower body involved with explosive vertical displacement. The Vertec (Sports Imports, Hiliard, OH 43026) is a common tool used to measure vertical displacement. The force plate is another way to record power with a countermovement vertical jump, which calculates ground reaction forces, peak power and average power. The 3-camera motion analysis system measures the displacement of the center of mass and is considered the gold standard of measuring vertical jump height [51]. The Just Jump system (Probotics, Huntsville, AL 35802) is a contact mat that calculates the amount of time the performer is off the ground during a vertical jump. Contact mats are tools used to estimate vertical jump height by measuring the flight time. In one study, using 40 college aged students, Just Jump was found to be more accurate in measuring vertical jump height than the vertec in comparison with the 3-camera motion analysis system [51]. In another study, 480 young subjects aged 7-11, were used to compare the difference in vertical jump height measured by the Vertec and Just Jump system [52]. The difference was found to average .95 inches, with consistently higher scores from the Just Jump system [52]. Isaacs et al found the Just Jump system to be accurate, efficient and convenient and therefore, superior to testing with the vertec due to the coordination involved [52]. From vertical jump height, peak power output, in watts, can be estimated from the Harman equation, $(61.9 \times \text{jump height in cm}) + (36 \times \text{body mass in kg}) + 1822$ [48]. One study examined the precision of various power equations using the vertical jump height and peak power measured by a force plate, and then compared to estimated peak power equations with over 800 secondary school students. In this study, the Harman equation was found to be precise, reaching 3.6-4.1% accuracy [53].

Evidence supports that CMJ is an effective and non-fatiguing tool for monitoring athletes during the competitive season [4]. Current research shows that power measures are useful in

monitoring long term, low frequency fatigue [4-6]. In a study measuring effects of aggressive training overload in seven rugby players, vertical jump was significantly decreased after the training stimulus and recovered after adequate rest was provided [5]. A study done by Kraemer et al showed significant decreases in vertical jump displacement and speed in starters of the Penn State male soccer players from pre-season measurements to late season measurements [6], however this study failed to link vertical jump decrements to markers of overtraining.

PSYCHOMOTOR SPEED

The use of psychomotor speed to determine early signs of overtraining has recently been introduced to the literature, and is an area that needs further investigation. Psychomotor speed is defined as the ability to rapidly and fluently perform body motor movements (movement of fingers, hands, legs, etc.). Speed of limb movement, movement time and reaction time all fall under the umbrella of psychomotor speed. It can be argued that psychomotor speed will decrease in overtrained athletes due to the fact that they often report related symptoms such as concentration problems, cognitive complaints and memory problems [3]. The Quick Board (The Quick Board L.L.C., Memphis, TN) was the testing tool of choice for measuring psychomotor speed. It is computerized, which fits the testing criteria of objective, not able to be manipulated or overly physically demanding, applicable in training sessions, and affordable. The Quick Board allows for the study of reaction time and speed of limb movement in a controlled, repeatable manner.

Only a few studies currently exist that have studied the effects of fatigue on psychomotor speed. One study induced aggressive overload in an attempt to identify early markers of fatigue. The sample included seven well trained cyclists who underwent an increase of training volume by 107% for two weeks. The major finding was that maximal HR, peak power output and maximal lactate did not change significantly from pre-training to post-training, but difficult finger-precuing reaction time increased. Easy protocols were not affected in the overreached individuals [7]. Similarly, Nederhof et al tested cyclists by measuring the effect of an intensive two week training

camp on different markers of overtraining. They found longer reaction times in functionally overreached cyclists than the control group, however, results were insignificant [8].

Lack of sleep can negatively impact fine motor skills, cognitive functioning and the ability to concentrate which would therefore negatively impact reaction time or speed of limb movement [54]. Overtraining has repeatedly been linked to sleep disorders [29]. Central fatigue during maximum voluntary rate accounts for a decline in movement rate from 7-9 seconds and continuing decline through the 20 second finger movements at maximum voluntary rate [55]. Therefore, it may be advantageous to limit data collection on rate of limb movement to 8 seconds or less.

QUANTIFICATION OF TRAINING STIMULUS

Type, duration and intensity of training stimulus affect the degree of fatigue experienced by the athlete. Part of diagnosing overtraining in athletes involves correlating symptoms to training load [44]. Within studies on overtraining, there has been an absence of accurate reporting of training quantity and quality [2] and lack of a uniform system of measurement for training load. One reported method, the TRIMP method, involves multiplying the average heart rate by duration of the session. Foster has described another method where RPE is multiplied by duration of the session in minutes. The product, sRPE, is represented in arbitrary units [56].

Polar TEAM heart rate monitoring system (Polar Electro Oy, Kempele, Finland) is gaining popularity in monitoring exercise-induced fatigue. Extensive information regarding training load calculated by HR monitors can be retrieved via the Polar TEAM training software and includes average HR, overall time spent exercising in a training session or game, time spent in designated heart rate zones, predicted fatigue based on training intensity, and training load. Training load is an arbitrary number estimated by the Polar TEAM training software using duration and intensity of a training session. Intensity is based from HR and the TL formula takes age, gender, weight, height, $VO_2\text{max}$, resting and max HR into account [57]. These variables help individualize and accurately estimate training load more so than the other methods.

LACK OF DEFINITIVE FINDINGS ON OVERTRAINING

There are specific gaps within the area of overtraining research that limit conclusions from being drawn on the diagnosis of overtraining. A review article by Halson and Jeukendrup point out the following reasons for a lack of definitive findings on the topic of overtraining: variable definitions of overtraining/overreaching which makes comparing results impossible, no standard method of diagnosis, many studies don't monitor performance decrements which is the only method to definitively diagnose overreaching and overtraining, many studies only test before and after training stimulus rather than during, quality and quantity of training stimulus is not accurately recorded in some studies which limits knowledge of the path to overreaching, and lastly, individuals differ in their response to intense training [2].

METHODS AND MATERIALS

EXPERIMENTAL DESIGN

A longitudinal study was used to determine which of three performance test results, VJ, PPO or RT, would be better predictors of early signs of overtraining through correlation with the accepted markers of overtraining. Over the course of the 2011 competitive season for the University of Louisville's women's soccer team, CMJ and RT were tested once per week. From these two tests, three performance results, PPO, RT and VJ were obtained and used to correlate with fatigue markers including, TL, resting HR, WT [6], RPE [9], and DALDA. WT, TL, and RPE were collected on training and game days, while resting HR was measured and recorded daily. DALDA, RT, PPO and VJ were completed weekly. These variables were recorded over a 12 week period during the competitive season of the women's soccer team from August 4th to October 26th.

Table 1

Timing of Data Collection

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Training Load		X	X	X	X		X
RPE		X	X	X	X		X
Resting HR	X	X	X	X	X	X	X
Weight		X	X	X	X		X
DALDA		X					
RT			X				
CMJ			X				

**CMJ= countermovement jump, RPE= rating of perceived exertion, DALDA= Daily Analyses of*

Life Demands for Athletes, RT= reaction time, HR= heart rate

Table 1 outlines the weekly timeline of data collection. Mondays were primarily rest days so TL, RPE, or WT were not collected those days. Starters did not practice most Saturdays, the day in between games, so the limited data recorded on Saturdays was not used. Performance testing was done immediately before practice two days after the day of rest. Ideally, performance testing would have been done the day immediately after the day of rest, but the practice schedule and coaches' decisions did not allow for it. VJ, PPO, RT and DALDA were completed once per week.

Toward the end of the season, the practice schedule was not consistent because the coaching staff permitted more rest for the subjects to allow for recovery. Therefore, the time of data collection varied toward the end of the season due to the inconsistent practice schedule. DALDA was collected at 6:40 a.m. on Tuesdays with the exception of weeks 7, 9, 10 and 11, when the data was collected on a Monday or Wednesday at 9:00 a.m. However, DALDA was always collected on the day after a day of rest. RT and CMJ were primarily performed on Wednesdays at 9:30 a.m. However, RT and CMJ were performed on a Tuesday or Thursday during week 3, 4, and 11 and on a Tuesday at 7:30 a.m. during week 1. During week 4, the original Quick Board failed. The new one arrived and was able to be used on Thursday that week. Week 4 was the only week that RT was done on a different day than CMJ.

Subjects

Seventeen players of the University of Louisville's women's soccer team were used as the subjects in this study. The subjects were aged between 17 and 21 years with an average age of 18.7 ± 1.2 years. Baseline measurements for all independent variables and dependent variables, except for RPE and TL, were taken on the subjects at the beginning of pre-season. The subjects were required to be members of the women's varsity squad. All red shirt members and goalkeepers were excluded from the study.

Procedures

All subjects signed consent forms approved by the University of Louisville Institutional Review Boards and participation was voluntary. Baseline measurements were taken at the beginning of pre-season including height, WT, body composition, resting HR, DALDA and an estimated VO_2max . Baseline performance tests on the CMJ and RT were conducted at the beginning of pre-season, before the start of training sessions and games. Two weeks after the baseline measurements were taken, CMJ and RT were then tested once a week for the next 11 weeks of the subjects' competitive season. The performance tests were conducted in Cardinal Park (University of Louisville, Louisville, KY), outside the locker room, before practice. Resting HR was self-reported by the subjects every day of their competitive season. Only the resting HRs collected on the days of which the performance testing was done were used in the data analysis. TL, analyzed by the Polar TEAM (Polar Electro Oy, Kempele, Finland) heart rate monitoring system, was monitored and recorded during every practice and competition. The subjects' RPE, from the Borg scale, was self-reported immediately after every training session and competition. The DALDA questionnaire was completed by the subjects before the first practice of the week on a weekly basis. WT was recorded every day before practice. Only the WT taken on the days of performance testing was used in the data analysis. If WT was missing that day, the most recent prior WT was used for data analysis. After a standardized 15 minute warm-up, the subjects performed the CMJ and RT tests before the start of practice that day to avoid fatigue incurred from the practice session. CMJ and RT were performed on a weekly basis, before practice, two days after the complete day of rest. The performance tests were done back to back with no specified order of testing, with the exception of week 4, when the tests were done on consecutive days rather than the same day due to equipment failure. The graduate student and University of Louisville's Sports Performance staff administered all performance tests and collect all data throughout the study.

Maximal Aerobic Power

Maximal aerobic power was collected once, as a baseline measurement, before training sessions and competitions began. Maximal aerobic power, quantified as VO_2max was estimated from the subjects' 3k times. The subjects ran the time trial around the University athletics cardio path at Cardinal Park. A formula, cited by Jack Daniels, was used to estimate VO_2max from the subjects' times [58].

Weight and Body Composition

WT was obtained and rounded to the nearest tenth of a kilogram by the Mettler Toledo: WeighSouth WSI 600 person scale (Amarillo, TX). WT was collected every day the subjects practiced, just before the training session started. Body composition measurements were taken on each subject as a baseline measurement at the start of the study and then repeated halfway through the season for a total of two measurements. The same experienced tester, a member of the University of Louisville's Sports Performance staff, used skin fold calipers to calculate body composition. The thickness of the subjects' subcutaneous fat in millimeters at seven sites on the subject's right side was measured by a RH 15911 Harpenden skinfold caliper (Baty International, West Sussex, United Kingdom). The seven sites included the chest, axilla, triceps, subscapula, suprailiac, thigh and abdominal. The Jackson-Pollock and the Siri equations will be used in the estimation of body density from the sum of seven sites and percentage of body fat, respectively. The specific population selected for the Jackson-Pollock and the Siri equations will be "female athletes from 18-61 years old", and "white female from 18-59 years old", respectively. Body mass used to calculate body fat percentage was obtained and rounded to the nearest 0.1 lb using the HD-351 digital weight scale (Tanita Corporation, Tokyo, Japan), which was a different scale than what was used for daily weigh ins.

Psychomotor Speed

RT was measured using the Quick Board HD sensor board, shown in Figure 1, developed by The Quick Board, L.L.C (Memphis, TN). The board laid flat on the ground and

consisted of five high impact sensors located in the upper right and left, lower right and left, and center position. The mat was connected to a control device called the Quick Board Pushbutton Control Panel by a power cord. The control device provided visual stimuli (i.e., five bright LED lights that correspond to the five foot pads) and feedback information about the results of the movement responses. The control pad also allowed for the command and programming of all sequences and drills. The 'react drill' measured RT by the use of randomly illuminated lights on the control device of which the user responded to as quickly as possible by touching the corresponding dot on the board with their foot. Once the correct dot was touched, another light was illuminated, triggering corresponding movement by the user. The time it took the subject to correctly touch eight dots was recorded, rounded to the nearest one hundredth of a second. Subjects completed two trials of the 'react drill'. There was a minimum of 15 seconds of rest between attempts and the best time was recorded. Subjects had one day of three to five trials to familiarize themselves with the Quick Board upon arriving to campus. The subjects then had two additional days for baseline testing with RT on the Quick Board. Each subject had two trials on each day and their best time was used as their baseline measurement.

The performance tests were performed just after a 15 minute standardized warm-up before the training begins. The standardized warm-up consisted of a two minute jogging period followed by dynamic stretching of primary muscle groups of the lower body (quadriceps, hamstrings, gluteus maximus, gastrocnemius and soleus). Leg swings, a ballistic type of stretching, two 30yd build up sprints, two maximum squat jumps followed the dynamic stretching period.

Figure 1

The Quick Board LLC

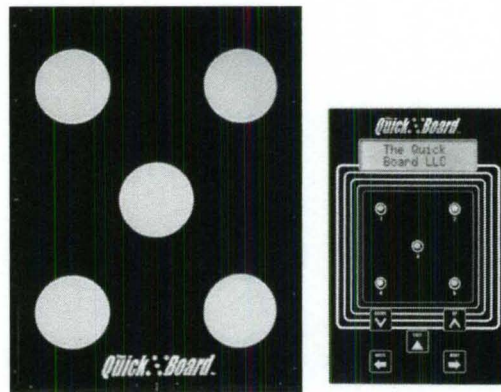
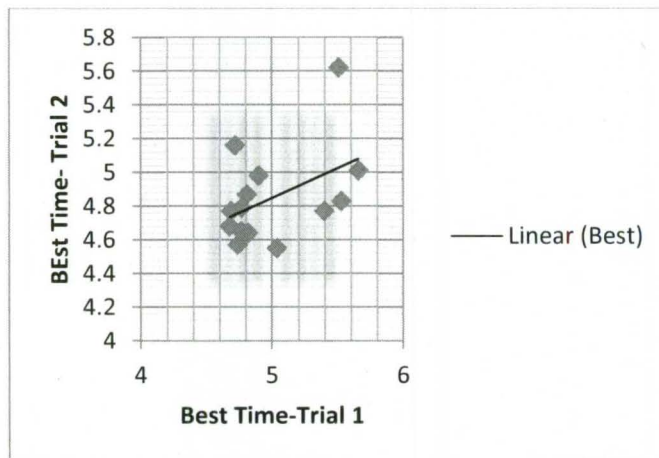


Figure 2

Test/Re-Test Scatterplot



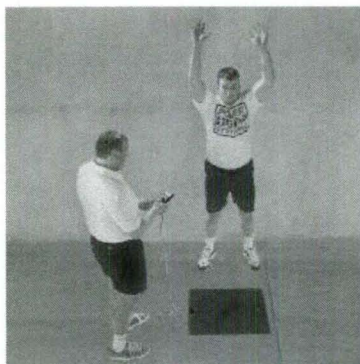
University of Louisville field hockey players were used to test the reliability of the RT protocol on the Quick Board and results are shown in Figure 2. A total of 14 subjects were used and each subject completed two trials twice in the same day with 20 minutes in between trials. Cronbach's alpha was 0.61 ($p = 0.05$) and the single measures ICC was 0.44 ($p = 0.05$). The specific protocol used for the study proved to be significant and moderately reliable.

Counter Movement Vertical Jump

The CMJ was performed by starting from a standing position, then flexing down to a semi squat position and then, without pausing, explosively extending the ankle, knee and hip joint to produce a maximum jump, as shown in Figure 3. Arm-swing has been found to increase jump height [59]. Subjects were instructed to swing arms naturally backward as they squat and then swing them forward as they explode into the jump, extending them overhead at the peak height as if reaching for something. This movement was performed on a contact mat, called the Just Jump System (Probotics Inc., Huntsville, AL), which measured the flight time from foot take off to landing. The Just Jump system then estimated VJ from flight time. Two trials were given for each subject with a minimum of 15 seconds rest between trials. The highest VJ was recorded. Because the contact mat estimated VJ based on air time, landing technique was critical to teach and keep consistent. After the explosive extension of the hips, knees and ankles which produced the jump, the joints should remain extended for the landing. Any degree of flexion in the knees or hips prior to landing delayed contact of feet with the mat and increased air time which would result in overestimation of the height jumped [52]. All subjects were instructed on proper jumping and landing technique. The CMJ test was performed once a week, in conjunction with RT, after the standardized 15 minute warm-up. PPO, estimated from the subjects' WT using the Harman Equation, and VJ were used as performance variables in correlation with the collected markers of fatigue.

Figure 3

The Countermovement Jump using the Just Jump System



Training Load

Each subject wore a Polar HR monitor (Polar Electro Oy, Kempele, Finland) during every practice and game. The team used the Polar TEAM HR monitoring system which included a HR monitor and a software program which recorded and analyzed the percentage of maximum HR and time spent at various HR zones. The system used a formula to calculate training load which is based on the individual's age, gender, height, WT, resting HR, maximum HR, average training intensity (based on HR) and time training [57]. TL is an arbitrary number that directly represented the intensity and time of the training session or competition. TL was recorded after each practice and game and each TL was used to calculate the weekly average. The weekly average was the number used for correlation with results of the performance tests. If players missed a practice due to injury, a value of zero was used for the TL that day. If players practiced but the HR monitors failed to give a TL for the day, a missing value, or blank, was given for that day to avoid influencing the average as a zero would.

Resting Heart Rate

Resting HR was measured and recorded on a daily basis by the subjects. The graduate student collected and recorded the subjects' resting HR weekly. Subjects were advised to count

their heart beats for 15 seconds upon waking and while still laying in bed. The numbers were then multiplied by four to indicate resting HR for the day. Only the resting HR collected on the days which the performance testing was done was used in statistical analysis. If no resting HR was collected that day, the most recent prior resting HR was used.

Psychological Questionnaire

Subjects completed the DALDA questionnaire weekly to capture stress experienced by the subjects during the last week. This scale consisted of two sections with the nine items on the first section indicating sources of stress and the twenty five items on the second section identifying stress symptoms. The definitions of the sections and instructions on how to correctly fill out the questionnaires were supplied to the subjects and kept with them for the entirety of the study. The answer sheets were completed by the subjects in their locker room the morning after the day of rest at approximately 6:40am. The subjects rated each item as being 'worse than normal', 'normal' or 'better than normal'. The total number of responses in each category was recorded, but the total number of 'worse than normal' answers for both sections (A and B) were used as markers of fatigue in the data analysis.

RPE

The subjects' RPE, using the Borg scale as depicted in Figure 4, was self-reported immediately following every training session and game. The subjects' individual data sheets were kept in their lockers and subjects were advised to record their RPE as soon as they returned to the locker room after practices and games. Borg's RPE, 6 through 20 scale was used. A score of 6 represents no exertion at all and a score of 20 represents maximal exertion. The subjects were advised to take their whole body's level of effort and exhaustion into account when reporting their RPE.

Figure 4

Borg's RPE Scale

Borg's RPE Scale	
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (Heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Borg RPE scale
© Gunnar Borg, 1970, 1985, 1994, 1996

STATISTICAL ANALYSIS

Summary statistics were calculated for the primary outcomes (VJ, PPO and RT) and all other collected covariates (WT, RPE, RPE:TL, TL, resting HR, DALDAA and DALDAB). Data was summarized via means and standard deviations/standard errors for numeric data and counts with percentages for categorical data. Graphical inspection of data included the examination of subject-specific and average line plots to track performance on the primary outcomes and the measured covariates over time as well as scatterplots to evaluate associations among outcome variables and covariates.

The primary hypothesis concerned the relationship between performance measures (VJ, PPO and RT) and a set of covariates (WT, TL, RPE, etc.). Supplemented by the graphical inspection scatterplots of outcomes against covariates, simple and partial correlation analyses were conducted to estimate and test the strength of said relationships. Additionally, simple and multiple linear models (regression and mixed effects) were fitted to provide further information about the nature of relationships between outcomes and covariates. Violations of the assumptions required for correlation and regression analyses (normality, linearity, homogeneity of

variance) induced the utilization of nonparametric correlation methods (Spearman and Kendall coefficients) and more general models such as generalized linear, generalized least squares, and non-linear models.

The primary interest in these models was to identify and estimate changes in performance (VJ, PPO, RT) over time, to estimate relationships between performance and the markers of fatigue, and to examine how these relationships change over the course of a competitive season. The above-mentioned analyses were supplemented with methods for longitudinal data (time series, linear mixed effects models).

RESULTS

SUBJECTS

Seventeen female varsity soccer players (aged 18.8 ± 1.2 years) participated in the study. All were members of the University of Louisville Women's Soccer team and all were healthy and free of injuries that would keep them from practicing at the start of the season. Six were midfielders, six were forwards and five were defenders. Goalkeepers were excluded from the study. Six were freshmen, eight were sophomores, one was a junior and two were seniors. Some missing data occurred in performing weekly RT or CMJ testing due to injuries, but those individuals were not excluded from the study. Out of the all possible RT tests, 11.8% were missing: 75% were missing due to injuries and 25% were missed due to class conflicts. Out of the 12.7% missing CMJ tests, 85% were due to injury and 15% were due to class conflicts. Out of all TL recorded, 28.5% were missing in this study which is the most significant missing variable. Of the resting HRs used for data analysis, 9.8% were missing and had to be substituted by the most recent prior resting HR recorded. Out of all possible RPE recordings, 6.4% were missing. Out of all DALDA responses, 2.0% were missing.

Summer Training

Subjects self-reported their summer activity, presented in Table 2, in order to capture the subjects' baseline values in terms of training load and fatigue. Summer activity was quantified by number of games played per week and time spent per week practicing soccer, lifting weights and conditioning.

Table 2Summer Training History

Summer Training	Range	Mean	SD
Hours/Week: Soccer	2-23	8.5	5.0
Hours/Week: S&C	3-18	7.8	3.3
Games/Week	0-7	1.6	1.9
Weeks Injured (N=8)	.3-36	8.8	13.5

**S&C= strength and conditioning training, N= sample size, SD= standard deviation*

The subjects reported an average of 1.6 ± 1.9 games per week. They reported an average of 8.5 ± 5 hours per week playing soccer in either a team or individual setting. An average time of 7.8 ± 3.3 hours per week was reported for time spent lifting and conditioning. Of the 17 subjects, eight reported that they suffered an injury over the summer. The eight subjects who sustained an injury over the summer averaged 8.7 ± 13.5 weeks of limited activity. Limitations were defined as no activity at all, no impact, no running or playing, no heavy lifting, and no change of direction. The summer activity compares to in-season averages of 20 hours per week playing soccer, two hours per week spent weight training and 1.73 games per week with the average game lasting 103 minutes.

Baseline Measurements

Table 3 illustrates the baseline measurements including anthropometrics and performance. The subjects weighed 61.9 ± 6.2 kilograms, were 169.2 ± 6.4 centimeters tall, had 16.8 ± 2.7 percent body fat and averaged 44.7 ± 2.8 ml/kg/min maximal oxygen consumption. The baseline resting HR was 57.7 ± 11 beats per minute. RT averaged to 4.93 ± 0.28 on the Quick Board. PPO calculated by the Harman equation [48] estimated from the subjects' VJ averaged 7207.9 ± 510.2 watts and the VJ averaged 51.1 ± 6.1 centimeters measured by the Just Jump System. Baseline psychological state, measured by DALDA, was taken August 3rd, the beginning of pre-season.

Table 3Baseline Measurements

Baseline Variables	Range	Mean	SD
Age (years)	17-21	18.8	1.2
Height (centimeters)	157.5-180.3	169.2	6.4
Weight (kilograms)	51.7-73.9	61.9	6.2
Body Fat Percentage	12.2-22	16.8	2.7
Lean Mass (kilograms)	44.4-61.3	51.4	4.8
Fat Mass (kilograms)	6.4-13.7	10.5	2.2
VO ₂ max (milliliters/kilogram/minute)	37.75-49.33	44.7	2.8
Reaction Time (seconds)	4.16-5.22	4.93	0.3
Vertical Jump (centimeters)	40.9-62.2	51.1	6.1
Peak Power Output (watts)	6394.5-8131.4	7207.9	510.2
Resting HR (beats/minute)	32-76	57.7	11.0
DALDA A ('a' responses)	0-4	1.5	1.2
DALDA B ('a' responses)	0-10	2.7	2.3

**VO₂max= maximum amount of O₂ consumed during exercise per kilogram bodyweight per*

minute, HR= heart rate, SD= standard deviation, DALDA= Daily Analyses of Life Demands for Athletes

Simple correlations were done on baseline measurements. Other than obvious correlations such as correlations between weight and lean mass, few relevant correlations were found. One of those few significant correlations was a negative relationship between age and number of 'worse than normal' responses on the sources of stress from the DALDA questionnaire ($r = -0.51$, $p = 0.05$).

Table 4

Change in Variables Over All Time Points

Estimates of Fixed Effects

Variable Name	Point Estimate	95% Confidence Interval	P-Value
Reaction Time (seconds)	-0.02	(-0.034, -0.005)	0.01
Vertical Jump (centimeters)	-0.03	(-0.41, 0.36)	0.91
Peak Power Output (watts)	2.7	(-26.35, 31.84)	0.85
Weight (kilograms)	0.07	(-0.31, 0.44)	0.71
DALDAA	-0.05	(-0.1, -0.01)	0.03
DALDAB	-0.18	(-0.29, -0.08)	0.00
Resting HR (beats/minute)	0.11	(-0.39, 0.61)	0.66
RPE	-0.19	(-0.36, -0.02)	0.03
Training Load	-0.45	(-3.50, 2.60)	0.77
RPE:TL	0.02	(-0.17, 0.21)	0.86
Body Fat Percent	-0.001	(-0.004, -0.002)	0.54
Fat Mass	-0.04	(-0.21, 0.2)	0.72
Lean Mass	0.14	(-0.4, 0.67)	0.61

*DALDA= Daily Analyses of Life Demands for Athletes, HR= heart rate, RPE= rating of perceived exertion, RPE:TL= ratio of rating of perceived exertion to training load

**Highlighted boxes denotes significant change in the variable over time

Table 4 denotes the average weekly change over the entire 12 week study of each variable. Confidence intervals and p-values are also recorded in table 4. Of particular note, RT decreased by an average of 0.02 seconds (-0.03, -0.01) per week. This decrease was significant (p= 0.01). DALDAA and DALDAB decreased by an average of -0.05 (-0.1, -0.01) and -0.18 (-0.29, -0.08) per week, respectively. Both decreases were significant (p= 0.05, 0.01, respectively). RPE decreased by an average of -0.19 (-0.36, -0.02). This decrease was significant (p= 0.05). Therefore, over the course of the study, RT improved by an average of 0.02 seconds per week,

stress levels represented by 'worse than normal' responses in DALDAA and DALDAB both decreased significantly, and RPE also decreased significantly.

Table 5

Relationship between Dependent Variables and Independent Variables Over all Time Points

Linear Mixed Method- DV vs. IV
Estimate of Fixed Effects

DV	IV	Point Estimate	95% CI	P-Value
RT (seconds)	DALDAA	0.07	(0.00, 0.13)	0.04
VJ (centimeters)	TL	0.03	(0.00, 0.03)	0.01
	RPE:TL	14.2	(5.4, 23)	0.00
	DALDAB	0.38	(0.15, 0.61)	0.00
PPO (watts)	TL	1.1	(0.34, 1.87)	0.01
	RPE:TL	878.11	(335.55, 1420.67)	0.00
	WT	21.91	(12.97, 30.86)	0.00
	DALDAB	23.09	(8.72, 37.47)	0.00

*RT= reaction time, VJ= vertical jump height, PPO= peak power output, TL= training load,

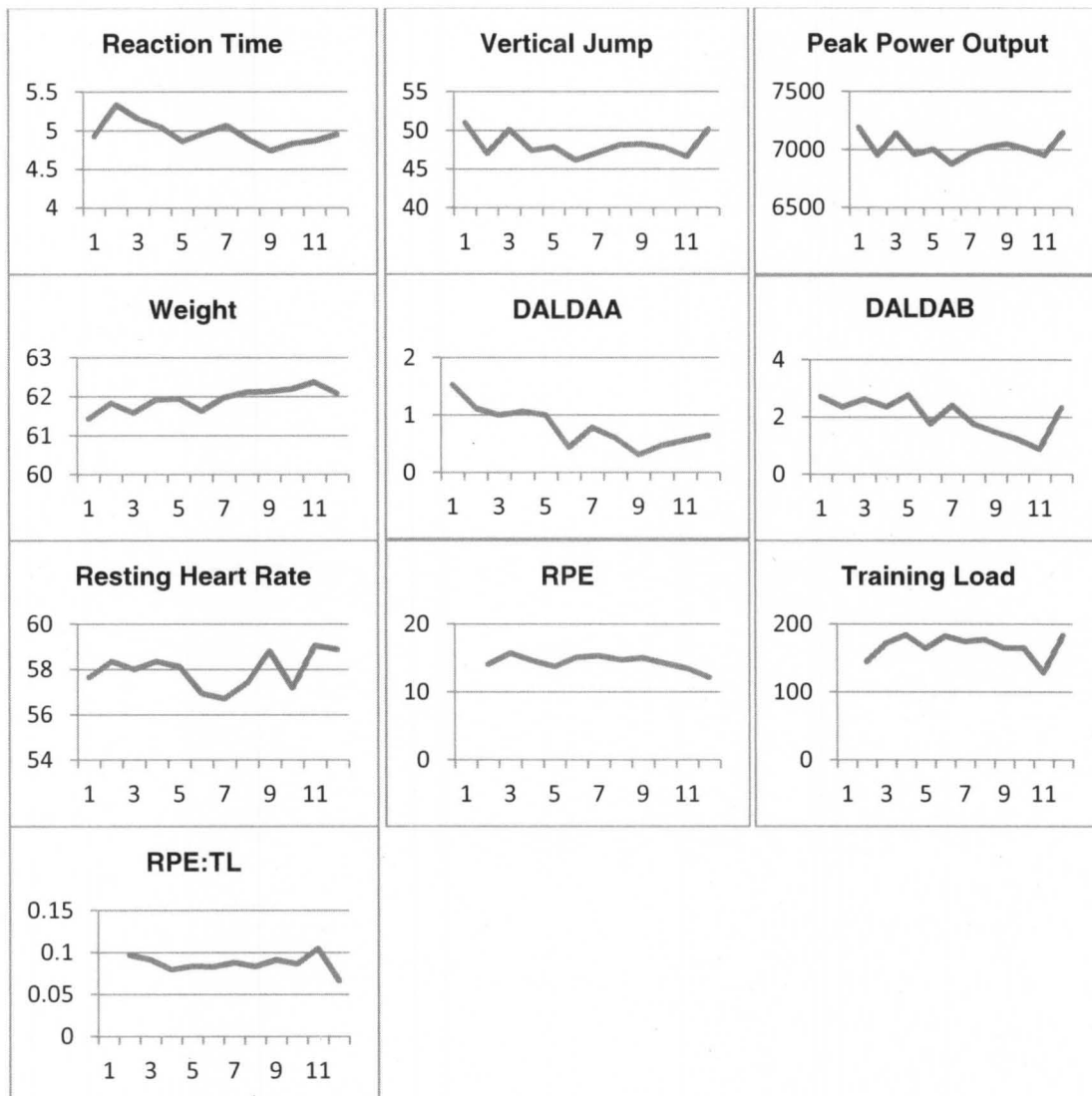
RPE:TL= ratio of rating of perceived exertion to training load, DALDA= Daily Analyses of Life Demands for Athletes; only significant correlations were included in Table 5

Table 5 shows the relationships between the overall changes in performance results with the overall changes in the markers of fatigue over the course of the season. There is a significant positive relationship between RT and number of 'worse than normal' responses in DALDAA. RT significantly increased ($p = 0.04$) by 0.07 seconds (0.0, 0.13) for every increase in DALDAA. Also important to note is the significant ($p = 0.01$) positive increase of 0.03 centimeters and 1.1 watts of VJ (0.00, 0.03) and PPO (0.34, 1.87) with TL. VJ and PPO positively and significantly ($p = 0.00$) increased by 14.2 centimeters (5.4, 23) and 878.11 watts (335.55, 1420.67), respectively, with RPE:TL ratio. VJ and PPO positively and significantly ($p = 0.00$) increased by 0.38 (0.15, 0.61) and 23.09 (8.72, 37.47) with increases in DALDAB. All independent variables were correlated with each dependent variable but these results were the only significant correlations identified with the linear mixed method analysis.

Bivariate correlations were analyzed on all independent variables against dependent variables, as raw numbers, split by week. Although some significant correlations were found, none exhibited presence of a fatigue marker in correlation with a decrement in performance except one. RT was significantly negatively related to WT during week 8 ($r = -0.65$, $p = 0.01$).

Figure 5

Variable Averages over Time



*DALDA= Daily Analyses of Life Demands for Athletes, RPE= rating of perceived exertion,

RPE:TL= ratio of rating of perceived exertion to training load

Table 6

Variable Weekly Averages and Change

WK	RT	Δ RT	VJ	Δ VJ	PPO	Δ PPO
0	4.93		51.03		7191.80	
1	5.33	0.42	47.04	-4.01	6954.45	-232.90
2	5.15	-0.21	50.14	3.25	7142.62	190.05
3	5.05	-0.45	47.42	-5.03	6958.16	-126.99
4	4.86	0.15	47.88	3.63	7002.38	46.06
5	4.97	0.16	46.15	-0.76	6873.51	-63.36
6	5.07	-0.33	47.14	-4.55	6969.59	-8.23
7	4.89	0.14	48.13	3.68	7025.93	43.26
8	4.74	-0.16	48.23	-0.28	7050.56	-17.53
9	4.83	0.11	47.78	-0.20	7004.45	-12.36
10	4.87	0.03	46.63	-0.15	6951.86	-3.93
11	4.95		50.19		7148.26	

*RT= reaction time in seconds, VJ= vertical jump height in centimeters, PPO= peak power output in watts, Δ = change

A. Dependent Variables

WK	WT	Δ WT	DALDA A	Δ DALDA A	DALDA B	Δ DALDA B	rHR	Δ rHR	RPE	Δ RPE	TL	Δ TL	RPE:TL	Δ RPE:TL
0	61.43		1.53		2.71		57.7							
1	61.83	0.4	1.12	0.50	2.35	1.33	58.4	0.9	14.1		145.2		9.69%	
2	61.58	-0.25	1.00	-0.06	2.63	0.75	58.0	-0.3	15.7	1.72	172.3	25.6	9.12%	0.21%
3	61.92	0.34	1.06	0.19	2.35	-0.31	58.4	-0.3	14.6	-1.07	184.3	19.8	7.92%	-1.75%
4	61.94	0.02	1.00	-0.18	2.76	0.41	58.1	-0.2	13.7	-0.76	164.1	-27.9	8.38%	-0.19%
5	61.63	-0.31	0.44	-0.47	1.76	-1.00	56.9	-1.2	15.1	1.40	182.6	32.8	8.29%	0.05%
6	61.98	0.35	0.79	0.29	2.41	0.65	56.7	-0.2	15.3	-0.19	174.6	-33.9	8.78%	0.60%
7	62.12	0.14	0.60	-0.24	1.75	-0.63	57.4	0.7	14.8	-0.69	177.5	18.7	8.31%	1.75%
8	62.13	0.01	0.31	-0.29	1.47	-0.38	58.8	1.4	15.0	0.42	164.5	-3.2	9.12%	-1.06%
9	62.20	0.06	0.47	0.18	1.24	-0.24	57.2	-1.7	14.2	-0.70	165.2	0.8	8.62%	-0.12%
10	62.38	0.18	0.56	0.06	0.88	-0.35	59.1	1.9	13.5	-0.56	128.5	-32.5	10.49%	2.49%
11	62.08		0.64		2.33		58.9		12.2		183.3		6.65%	

*WT= weight in kilograms, DALDA= the Daily Analyses of Life Demands for Athletes, rHR= resting heart rate, RPE= rating of perceived exertion, TL= training load, RPE:TL= ratio of rating of perceived exertion and training load

B. Independent Variables

*** The blue highlighted boxes denote presence of fatigue as a marker (as in decreased WT, increased resting HR, increase in RPE, increase in DALDAA and DALDAB, and an increase in RPE:TL) or as a decrement in performance (as an increase in RT or a decrease in VJ or PPO) from week to week. The italic, bold numbers denote a significance change from the week prior, $p < 0.05$.*

Table 6 shows the week's average, as well as the weekly change, of each variable. One sample T-tests were completed to identify significant change for each variable during each week. Bivariate correlations between dependent and independent variables were also completed. Changes in practice volume and intensity toward the end of the season impacted the data collected at that time. Part A displays the dependent variables' weekly changes and averages. There were significant decrements in performance in RT ($p = 0.01$), VJ ($p = 0.00$), and PPO ($p = 0.00$) from baseline (August 4th) to week 1 (August 16th). From week 1 to week 2, there were significant improvements in all three performance tests. Although many decrements in performance testing were observed, the only other significant decrements took place from week 2 to week 3 in PPO with a decrease of 126.99 ($p = 0.04$) and from week 4 to 5 in RT, with an increase in RT by 0.16 seconds ($p = 0.04$). The significant decrement in RT that occurred in week 5 accompanied insignificant decreases in VJ and PPO. This may be a sign that RT is a more sensitive test to fatigue.

Part B displays the independent variables' weekly changes and averages. The decrement of performance results in week 1 were accompanied by one significant marker of fatigue, an increase in 'worse than normal' responses in DALDAB by 1.33 ($p = 0.06$). There was a significant increase in RPE between week 1 and week 2 by 1.72 ($p = 0.02$). Change in TL significantly increased in week 2 ($p = 0.00$) and significantly decreased in week 10 ($p = 0.04$). Significant increase in WT occurred in week 1 ($p = 0.04$) and 6 ($p = 0.05$). There was a significant decrease in DALDAB ($p = 0.00$) from week 4 to week 8. No significant changes occurred in DALDAA or resting HR.

Table 7

Correlations between weekly change in DV and IV

Week	DV	IV	Pearson Correlation	P-Value
1	RT	WT	0.53	0.04
2	RT	DALDAA	0.56	0.03
		DALDAB	0.62	0.01
	VJ	DALDAA	0.73	0
	PPO	DALDAA	0.66	0.01
3	PPO	DALDAA	0.69	0.01
4	RT	RPE	-0.82	0
		RPE:TL	-0.64	0.01
	VJ	RPE	-0.79	0
		RPE:TL	-0.61	0.02
5	RT	WT	0.81	0
6	RT	WT	-0.57	0.04
	VJ	WT	-0.63	0.04
7	RT	WT	-0.6	0.01
	VJ	WT	-0.54	0.04
	PPO	WT	0.56	0.04
4-8	RT	DALDAA	0.65	0.01
	VJ	RPE	0.54	0.05
9	RT	WT	0.51	0.05

*RT= reaction time, VJ= vertical jump height, PPO= peak power output, WT= weight, DALDA= the Daily Analyses of Life Demands for Athletes, RPE= rating of perceived exertion, TL= training load, RPE:TL= ratio of rating of perceived exertion and training load

** The blue highlighted boxes denote correlation between a decrement in performance (as an increase in RT or decrease in VJ or PPO) and the presence of a fatigue marker (decreased WT, increased resting HR, increased RPE, increased DALDAA and DALDAB, and increased RPE:TL)

Bivariate correlations between the weekly change in dependent variables and independent variables revealed some important relations. From week 1 to week 2, RT significantly and positively correlated with DALDAA ($r = 0.56$, $p = 0.03$) and DALDAB ($r = 0.62$, $p = 0.01$). This finding supported the hypothesis. From week 3 to week 4, the change in VJ significantly and negatively correlated with the change in RPE ($r = -0.79$, $p = 0.0$) and RPE:TL ($r = -0.61$, $p = 0.02$). This finding was not consistent with the hypothesis but was consistent with the fact that the presence of fatigue, through elevated RPE and RPE:TL, negatively affects performance, measured by VJ. The change in RT significantly and negatively correlated with the

change in WT from week 5 to week 6 ($r = -0.57$, $p = 0.04$) and from week 6 to week 7 ($r = -0.6$, $p = 0.01$). Decreases in WT correlated with decrements in RT. Decreases in WT also significantly correlated with decrements in PPO ($r = 0.56$, $p = 0.04$) from week 6 to week 7. This finding supported the hypothesis. However, RT positively correlated with WT in week 1 ($r = 0.53$, $p = 0.04$), week 5 ($r = 0.81$, $p = 0.0$) and week 9 ($r = 0.51$, $p = 0.05$). Change in RT positively correlated with change in DALDAA from week 4 to week 8 ($r = 0.65$, $p = 0.01$), which supported the hypothesis. It is important to note that a significant decrease in DALDAB occurred between week 4 and week 8 which accompanied the significant positive correlation between RT and DALDAA during that same time period.

DISCUSSION

The purpose of this study was to examine whether decrements of performance in RT, PPO, or VJ would best correlate with the markers of fatigue associated with accumulated fatigue during the competitive soccer season. It was hypothesized that RT would best correlate with fatigue markers such as increased resting HR, increased RPE, increased RPE:TL, and an increase in DALDAA and DALDAB, while VJ and PPO would correlated more with WT and body compositional changes during the season. The findings show that RT declined significantly over time while VJ and PPO did not significantly change over the course of the season. RPE, DALDAA and DALDAB both declined significantly over time while RT was significantly and positively correlated to DALDAA. RT correlated with markers of fatigue more frequently than VJ and PPO.

If fatigue took place over the course of the season, there would be an increase in the markers of fatigue. Fatigue would be represented by a loss in WT [20, 31], elevated RPE [1], an increase in RPE:TL [13], a deviation, more likely an increase, in resting HR [34], and an increase in DALDAA and DALDAB 'worse than normal' responses [42] [40]. In this study, these specified representations of fatigue did not occur over the course of the season. Four variables showed significant change over the entirety of the study. A significant decrease was observed in DALDAA and DALDAB. The monotony of completing these questionnaires for 11 straight weeks may have influenced this change. RPE also significantly may have decreased which may have reflected the decrease in TL due to the adjustments the coaching staff made. RT significantly decreased over time. Changes the coaching staff made during season to help subjects recover

may have been the reason for not seeing accumulated fatigue over time (as would be indicated by the presence of fatigue markers). TL decreased over the course of the season, though not significantly. The decrease in TL is evidence that coaches made adjustments in training intensity and volume to avoid fatiguing the subjects. Given the adjustments the coaches made during the season to prevent overtraining, it would be beneficial to look at each week individually to see if there were correlations found between the presence of fatigue markers and decrements in performance.

RT has been used as a potential tool to monitor fatigue. Studies have shown decreased RT in fatigued athletes [41, 61]. RT significantly slowed in correlation with an increase in DALDAA and DALDAB in week 2 [See table 6], and in correlation with DALDAA between weeks 4 and 8. In addition, table 5 illustrates the overall significant positive correlation between RT and DALDAA over all time points. RT gets slower as the number of 'worse than normal' responses increase as well as decreases in both correlate with each other. These findings support one of the studies' hypotheses. Decrements in RT correlated with WT loss in week 6 and week 7, but RT correlated with WT gain in week 1, 5 and 9 [See table 6]. Also in week 8, RT significantly correlated with WT loss in the correlation of raw numbers, split by week. Research shows conflicting results with WT as a marker of an overtraining. Some found no change in weight [23] while other studies have established weight loss as a significant marker of fatigue [20, 26]. A decrement in RT did not correlate with an increase in RPE, TL or RPE:TL overall or weekly, as the investigators hypothesized.

VJ has been shown to significantly decrease in one study with soccer players over the course of the season [6] while other studies involving judo athletes have found no change in VJ [62] in over a period of intensified training. In week 4, VJ was found to be significantly and negatively correlated with RPE and RPE:TL which provides evidence for presence of fatigue negatively affecting performance in VJ. However, in week 8, VJ and PPO show significant positive correlations with DALDAB, RPE:TL and TL. Over all time points, VJ and PPO also positively correlate with TL and RPE:TL. Therefore, VJ and PPO improved with an increase in

number of 'worse than normal' responses, increase of TL and increase in RPE:TL [table 5]. These results indicate that for the current study, VJ and PPO do not accurately capture the fatigue associated with an increase in stress, increase in TL, and increase in RPE:TL. No significant correlations occur with VJ and PPO with DALDAA and DALDAB that would prove that stress levels decrease performance in VJ and PPO. Because decrements in performance are often associated with mood disturbances in cases of fatigue and overtraining [21, 23, 44, 45], RT seems to be a better indicator of this fatigue marker than PPO and VJ.

The commonly cited criterion in literature for diagnosing overtrained athletes include a history of increased training volume and intensity [14, 44], an unexplained decrement in performance in combination with mood disturbances after recovery [21, 23, 44, 45] while proven otherwise healthy after clinical examinations and lab testing [14, 44] [46]. The subjects in this study were not found to be overtrained based on these criteria for diagnosis. Previous studies show that symptoms of overtraining can occur in the absence of overtraining [63, 64]. Also, an athlete can be overtrained but not present the symptoms [65]. Overall, literature states that there is that a fine line that separates the normal fatigue associated with regular training and the long term fatigue associated with overreaching [66]. Also, the markers of overtraining are somewhat obscure. The research shows conflicting analysis of WT in overtrained athletes. Research also shows that there are two types of overtraining and each has opposing affects on resting HR. A deviated resting HR from the normal pre-season baseline resting heart rate, either lower or higher, indicates the athlete may be experiencing the parasympathetic type or sympathetic overtraining syndrome, respectively. Therefore both higher and lower resting HR may indicate lasting fatigue.

In one study, 15% of 257 British elite athletes were found to be overtrained in a 12 month observation period. Fifty percent of the overtrained athletes were reported to developing overtrained status in a three month competitive phase [67]. Therefore, while research supports the fact that overtraining can be developed during a three month period, overtraining is unlikely in a controlled environment due to the precautions coaches make to avoid this. Although

decrements in performance in RT correlated with an increase in stress, the other markers of fatigue did not exhibit overall trends toward overtraining. Overtraining is unlikely to occur due to the precautions taken by athletic trainers and the sports performance staff. The coaching staff manipulated training intensity, volume, duration and frequency if fatigue was sensed. The athletes were given more days off toward the end of the study than in the beginning. The capacity for individuals to buffer stress can influence fatigue and mood disturbances experienced by the athlete. The subjects worked with a mental conditioning coach frequently and consistently throughout this study which may have increased their stress buffering capacity. The sports performance coach took specific precautions with the training as well. The subjects participated regularly in regeneration techniques such as hydrotherapy, both in a pool and cold whirlpool, massage, foam rolling, stretching, and nutrition supplements.

Overtraining is defined as an accumulation of training and/or non-training stress resulting in long term decrement in performance capacity with or without related signs and symptoms in which restoration of performance may take several weeks or months [2]. In this study, the presence of fatigue was examined after one day of recovery. An individual may be diagnosed as non-functionally overreached if the decrement in performance persists even after a pre-planned rest period. Therefore, the accumulated fatigue would be better described as a result of non-functional overreaching. Either way, the fatigue that persists after the given rest period will interfere with training sessions and games and may be detrimental to the teams' success. The number of days needed to rest versus the number of days you can increase training load without overreaching an individual is the relationship to monitor.

Limitations

There were some limitations in this study that were primarily due to the fact that this study was a field study so many variables could not be controlled for. Only 17 subjects participated in this study, which is a small sample size. However, this study was a pilot study. RPE and resting HR were primarily self reported and therefore, may not have been recorded truthfully or

consistently. Although one study concluded that time of day does not influence measures of anxiety and depression [68], the DALDA questionnaire was completed at 6:40 a.m. the day after a day of rest which may have influenced their perceived mood state. There were a total of 61 practices or games, where 6.4% RPE values were missing (unrecorded) and 28.5% TL values were missing (unrecorded), which resulted in 43.9% missing RPE:TL. Some of the troubles with the Polar HR monitors included misplacement of strap, slipping of the strap due to excess sweat, subjects forgetting to wear them or taking them off due to discomfort. The performance tests were performed by the subjects around 9:30 a.m. every Wednesday, after playing games on Friday and Sunday, taking Monday off and practicing early Tuesday morning. Ideally these performance tests would have been completed before any exercise and immediately after a day of rest. Tuesday's practice session may have influenced the level of fatigue captured on the results of the performance tests. Another limitation to this study was the inability to capture all stresses felt by the subjects. Each individual copes with stress differently. This study was unable to measure variation between subjects such as starters and non-starters, positional differences, weeks of heavy travel versus light travel and whether the team won or lost. Therefore, using the average would have diffused cases where overtraining may have existed.

CONCLUSION

The conclusion of this study points to a new promising method of monitoring fatigue during the competitive soccer season. The fact that RT alternated with VJ and PPO in weekly timing of significant decrements leads to the conclusion that the tests pick up on different markers of fatigue. In this study, due to the significant overall positive correlation between RT and DALDAA, RT seemed to be the better tool to monitor fatigue. Decrements in VJ and PPO did not significantly correlate with any marker of fatigue consistently. Future research should focus on the use of a control group (perhaps the non-starters or a team in the off-season) or studies on male subjects. This would magnify the physiological differences developed during the course of the season due to the intense training and stress that accompanies playing games every weekend and traveling. Another path deserving further exploration is the testing of limb speed, as another class of psychomotor speed, rather than reaction time. Limb speed may not include as much room for error and differences in random protocols.

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